

AFCRYO

CRYOCOOLER MEMBRANE TECHNOLOGY



Commercial Cryocoolers for use in HTS applications

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AFCryo is a joint Venture established in 2017 between
[Absolut System](#) and [Fabrum Solutions](#)
to provide large scale cryocooler designs and production

Contents

- ✓ Introduction – Fabrum Solutions and Absolut System experiences in cooling HTS applications
- ✓ Looking at industrial applications
- ✓ Characteristics of an industrial liquefier
- ✓ **AFCRYO** answer : Diaphragm pressure wave generator liquefier
- ✓ Summary



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- Location Christchurch, New Zealand
 - Founded in 2004
 - High precision manufacturing processes
 - 25 Employees
 - 2500 m² Office/WorkShop
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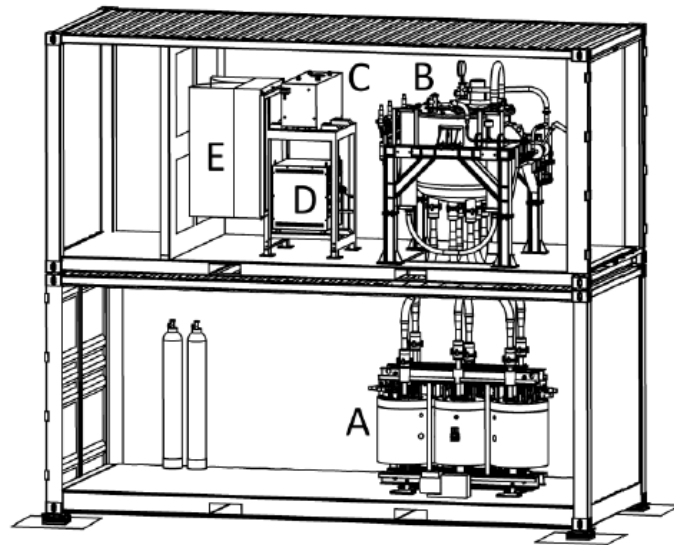
Single phase composite cryostats for 3-phases HTS transformer

- 1MVA 3-phases transformer 11kV/240V demonstrator run by IRL (Industrial Research Lab - NZ, now Callaghan Innovation), operated at 65K
- Both High and Low voltage windings used ReBCO conductors with iron core external to the cryogenic region
- Cryostat vacuum space was filled with glass microspheres, and continuously pumped with rotary pump. 60W cryostat losses (without current leads)
- 3 separated cryostats is not optimal for the heat leaks through the bushing (6 for HV and 4 for LV) compared to common cryostat for 3 phases, but it brings a lot of simplicity to the cryostat design and tests



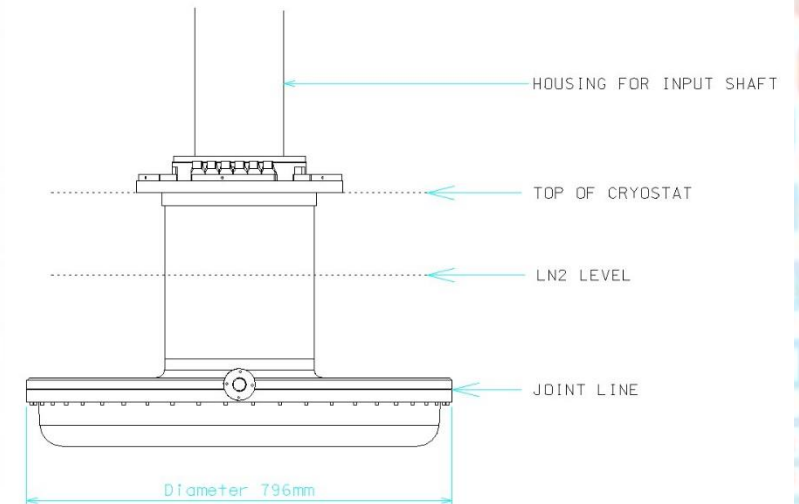
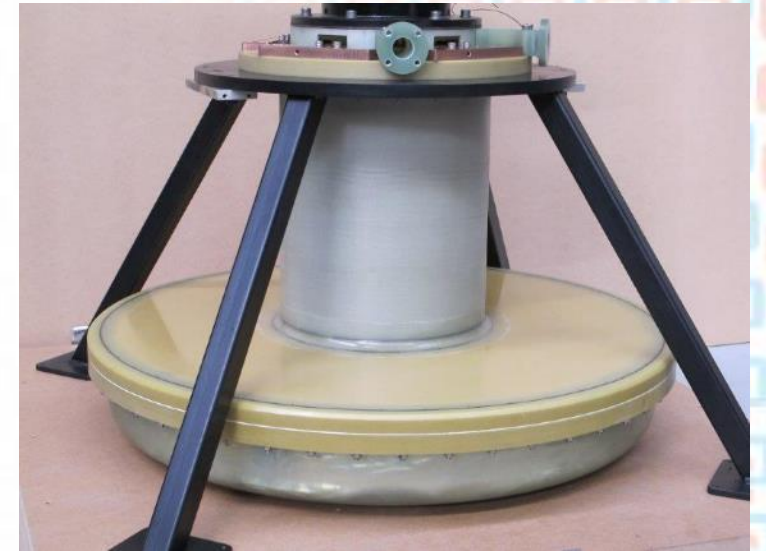
Single phase composite cryostats for 3-phases HTS transformer (cont'd)

- Transformer packed and designed with relocation in mind, making use of 6m long shipment containers (cryosystem container and 3 cryostats container)
- 65K subcooled LN2 cryosystem with natural convective flow refrigeration developed by Absolut System



Composite cryostat for LN2 cooled homopolar motor

- Motor designed using 2G, Roebel cable, carrying 5 kA, operated at 77K, Max shaft speed was 1800rpm
- The inverted mushroom cryostat has a total wall thickness of 21.5mm, including 9.5mm of vacuum insulation space
- The cryostat has a joint line on the perimeter of the mushroom to enable access to the homopolar rotor
- The joint line was designed to withstand direct contact with LN2, and withstand hydraulic pressures



Composite Dewar for AC Loss coil Test Facility

- SuperPower's calorimetric AC loss coil test facility aiming to determine the ac losses developed in prototype winding configurations of 2G HTS conductor architectures
- LN2 based
- Dewar able to handling coils up to 850 mm diameter and 600 mm height and losses from a few watts to up to 1500W
- Optimized for low background heat leak and mitigates any eddy current losses



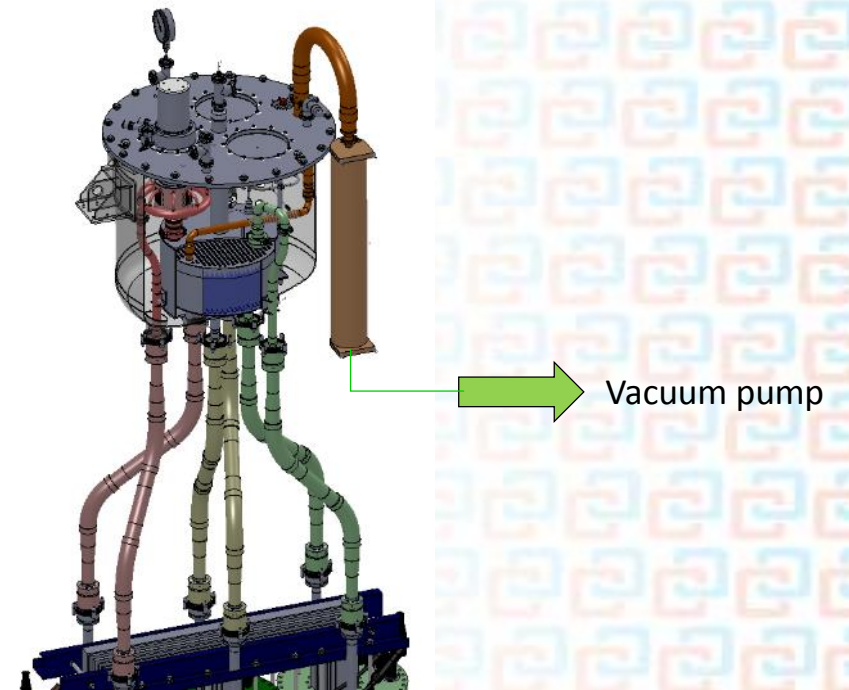
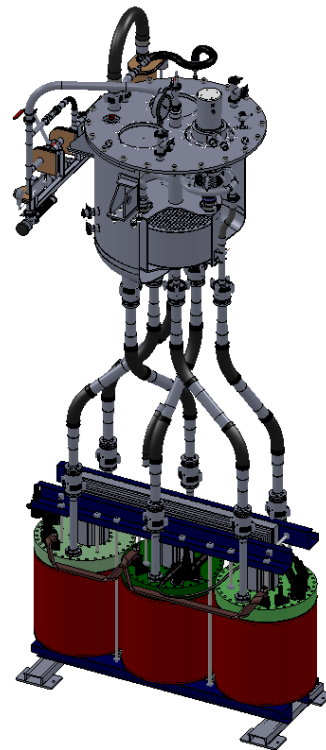


INNOVATIVE SOLUTIONS
**ABSOLUT
SYSTEM**

- Location Grenoble, France
 - Founded in 2010
 - Engineering and R&D Focus
 - 14 Employees
 - 700 m² Office/Laboratory
-

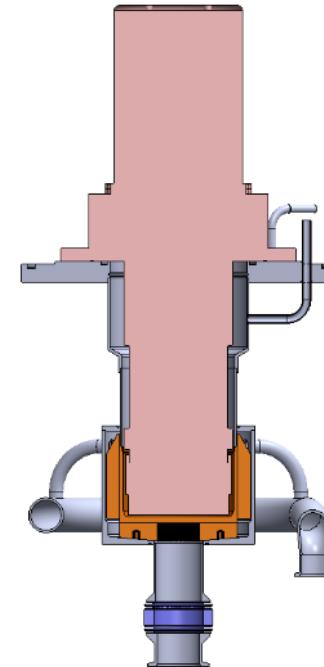
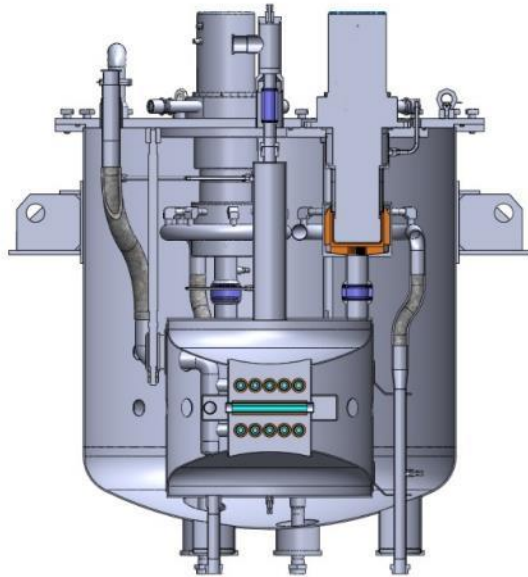
Fully automatized and reliable 65K subcooler for IRL / 3ph HTS transformer

- 1500W cooling power @ 65K is achieved by 3 GM CRYOMECH AL600 cryocoolers connected to LN2 thermosiphon circulation loop (no cryogenic circulator)
- 1 pumped LN2 sub-cooler heat exchanger in back-up of the GM coolers (used in case of failure or during GM cooler maintenance phases)



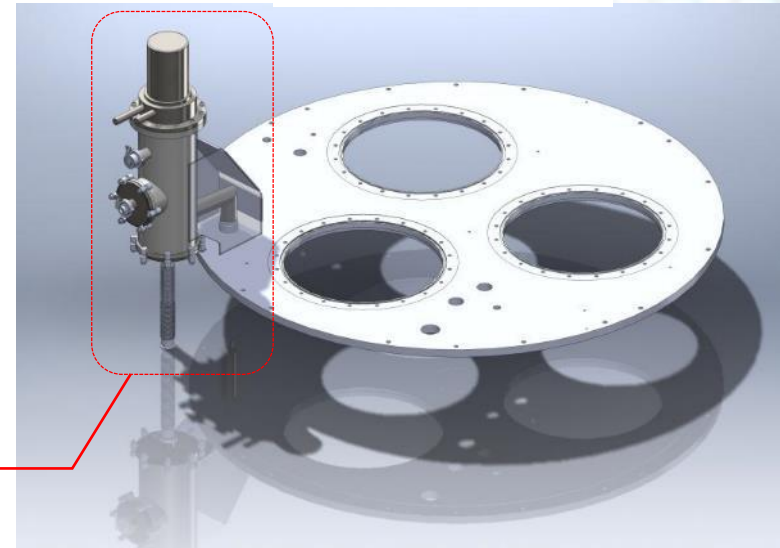
Fully automatized and reliable 65K subcooler for IRL / 3ph HTS transformer (cont'd)

- Baseline 3*AL600 GM cryorefrigerators are connected via a Thermal Link Assembly (TLA) to the thermosiphon
- Innovative TLA using annular heat pipe to allow thermal coupling and dismounting for maintenance of the cold head with system still in operation with external LN2 supply



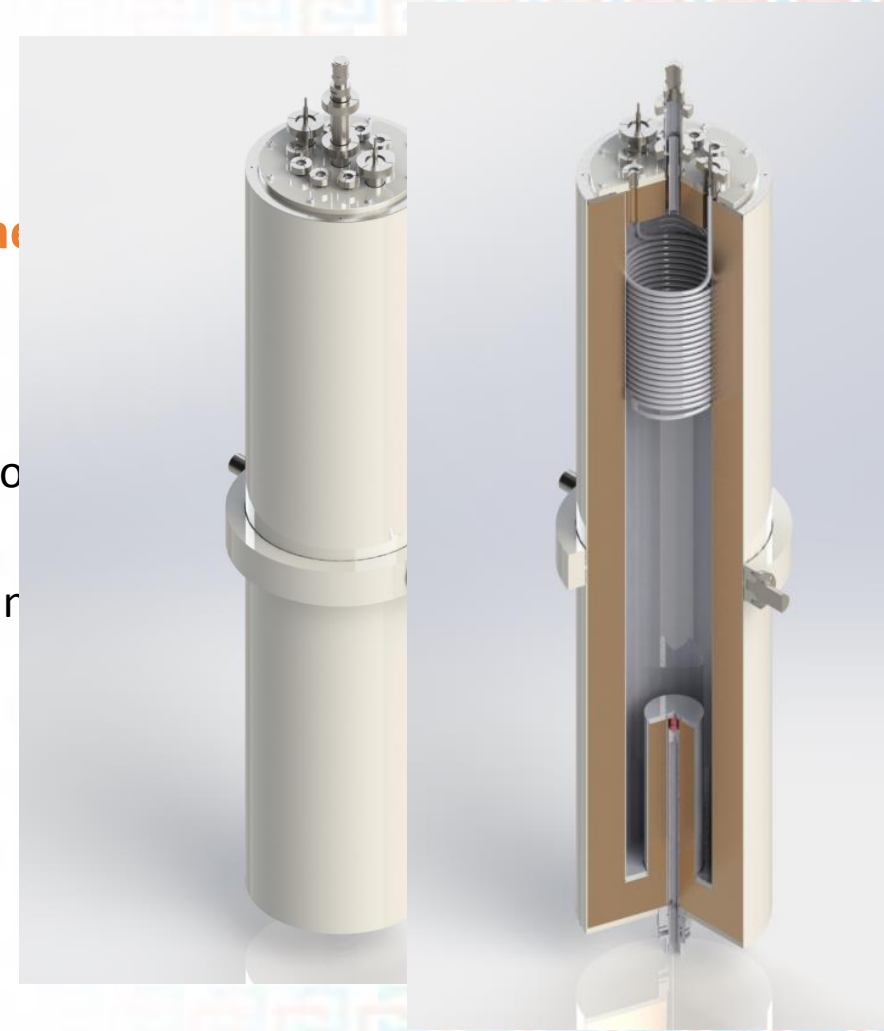
Nitrogen recondensing system for ECCOFLOW 3 phases HTS FCL

- 1 CRYOMECH GM AL600 cryocooler (500W/80K) with enhanced heat transfer area at cold tip for LN₂ Boil Off re-condensation by natural convection
- Dismountability for cold head maintenance
- System delivered to Air Liquide Advanced Technology



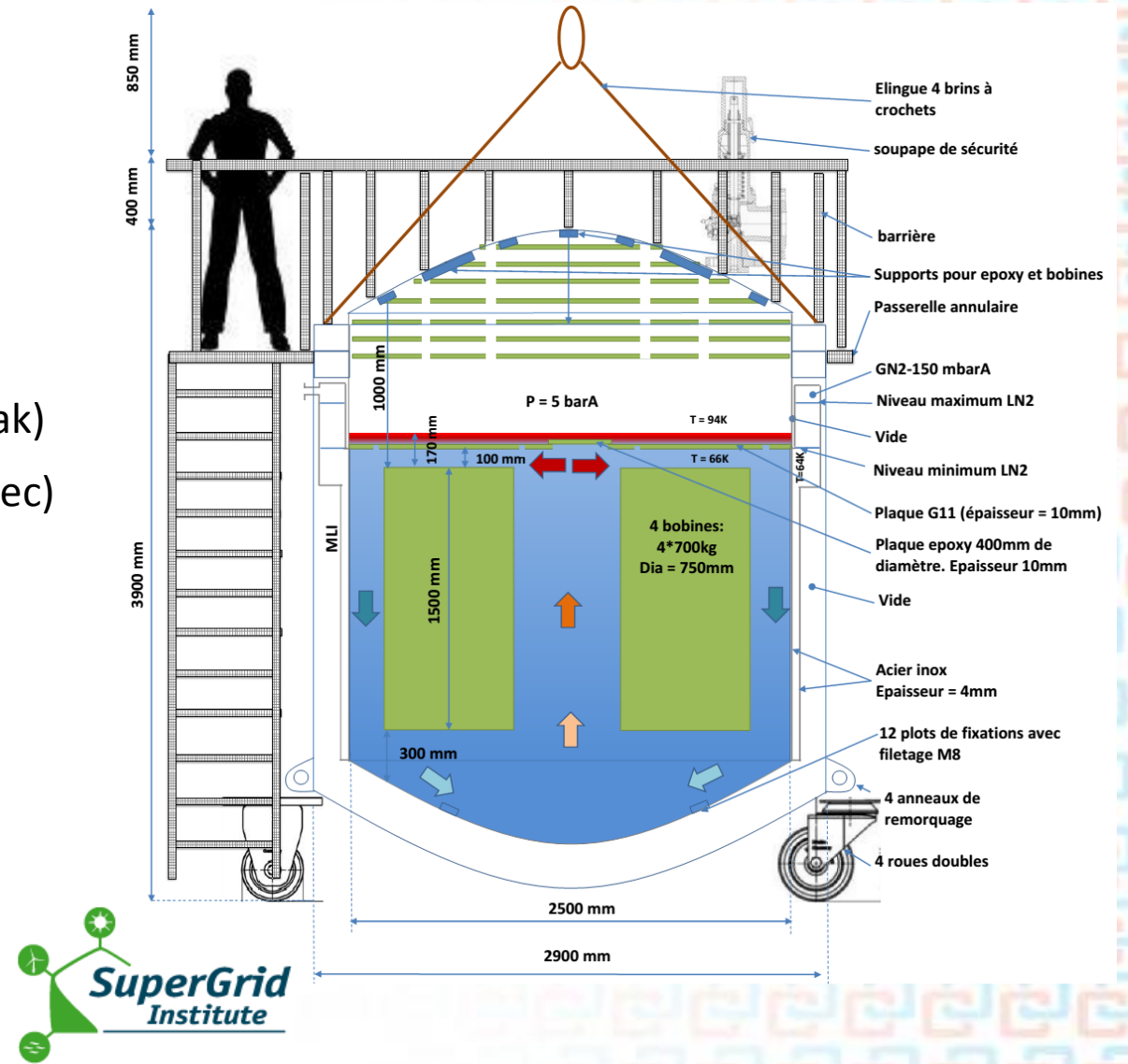
Subcooled forced flow pressurized Nitrogen cryostat for dielectric me

- Subcooled LN2 forced flow @ 5 bars / 77K
- Dry pumped flow option @ 65K
- 150 kV dielectric measures on isolators used in HTS cable application performed by ESPCI
- 2 meters height cryostat : SS inner shell, Polyurethane foam, G10 lin designed by ABSOLUT SYSTEM and manufactured by FABRUM



Study of HTS FCL and HVDC breaker

- Double wall LN2 cryostat
- 4 coils (700 kg each) operated at 5bars @ 68K
- 72.5 to 320 kV HV – nominal current 1.5 kA (15 kA peak)
- 13.2 MJ quench power (2 successive quenches at 10 sec)



Remote Helium cooling loop for MgB2 superconducting cable system

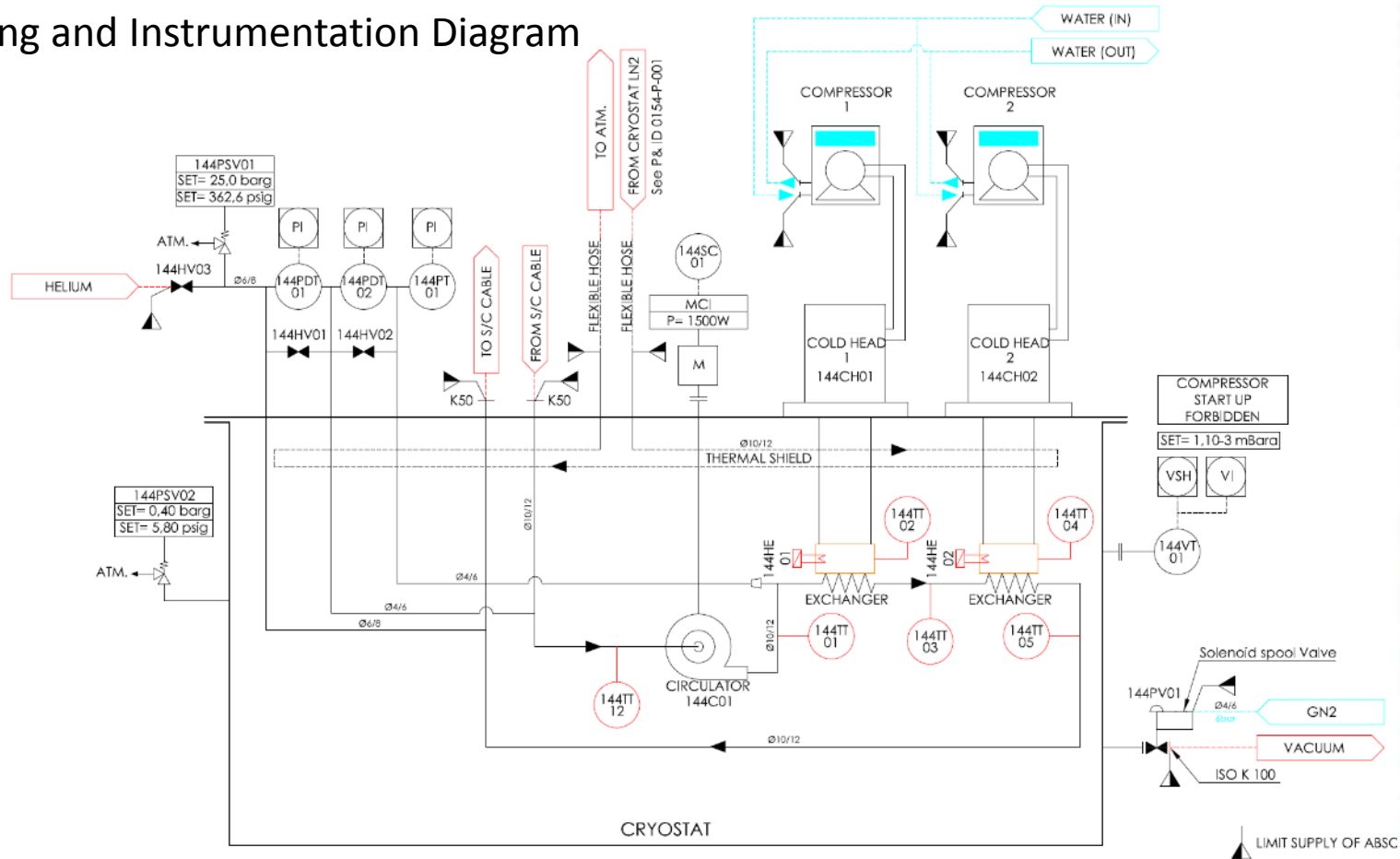
- Supercritical 20 bars helium forced flow loop @ 20K
- Helium mass flow rate of 10 g/s
- Cooling source composed of 2 CRYOMECH AL325 GM type cryocoolers
- Noordenwing type cryofan from CRYOZONE is used for the circulation
- Thermal shielding provided with lost LN2 loop forced flow
- **114W @ 20K net cooling power is distributed with 4.4 m flex lines**



20K cold box

Remote Helium cooling loop for MgB2 superconducting cable system (cont'd)

- Piping and Instrumentation Diagram



Remote Helium cooling loop for MgB2 superconducting cable system (cont'd)

- LN2 distribution box for :
 - 7bars subcooled 77K forced flow loop to the cable thermal shield
 - 1.4bars pressurized bath for the 20K cooler thermal shield and the cable current leads
- 600L LN2 dewar designed by ABSOLUT SYSTEM & manufactured by FABRUM. G10 inner wall, PU insulating foam and SS external liner



20K cold box & LN2 distribution box
at customer premises



30K Remote Helium cooling loop

- 80W @ 30K with 1 * AL325 GM cryocooler
- Room temperature compressor for the forced flow (and thus counter flow heat exchangers)
- MgB2 based HTS motor for JEUMONT Electric



50K Remote Helium cooling loops

- 43W @ 50K with 1 * AL 230 GM cryocooler
- Cold cryofan
- ISO5 class clean room compatible – 50 dBA
- IR detectors electro-optical characterization for SOFRADIR



➔ Remote Helium cooling loops can be scaled to 65-77K (but limited to few hundreds of Watts)

Market needs for industrial on-site liquefaction

Liquid Nitrogen (LIN) Solutions



- HTS applications for transformers and FCL's
 - Aircraft Tires on the Flight Line
 - Wheel & Brake Repair Facility
 - Landing Gear Struts
 - Recharging Cylinders
 - Inert Explosive Vapors within Fuel Tanks
 - Emergency Power Unit Purge & Test (F-16)
 - Optical Device Enclosures & Dome Lanterns
 - High Pressure Missile Tube Recharge
 - Industrial gas 'on-site' supply
-



Liquid Oxygen (LOX) Solutions

- Aviation Breathing Oxygen
 - Medical Breathing Oxygen
 - Welding & Cutting
 - Recharging Cylinders
-



LNG Marine Delivery

- Reliquefaction of methane boil-off during marine transportation
 - Scalability of units
 - 3kW to 15kW packages
-



Liquid Air

- High density (728:1)
 - Two times the density of compressed air resulting in extended operating times
 - Low operating pressures (70 – 125 PSI)
 - Significant safety benefit
 - Heat stress mitigation
-

Cryo Life Support Systems, LLC

Market requirements for Cryocooler Liquefaction Solution

- Low maintenance requirements = long operating periods
- Rapid deployment and re-deployment
 - Containerised and robust for airlift/trucking movements
 - Easy installation/connectivity
 - One push button operation to activate
 - Rapid cooldown cycle < 30 minutes
 - One button shutdown
 - Autonomous operation and infield fault diagnostic functionality
- Elevated net coefficient of performance (total input compressor/cooling power)
- Severe environmental conditions
- Automated load matching of output power
- Tolerant to vertical and angular movements (earthquakes and marine)
- Low-tech onsite servicing

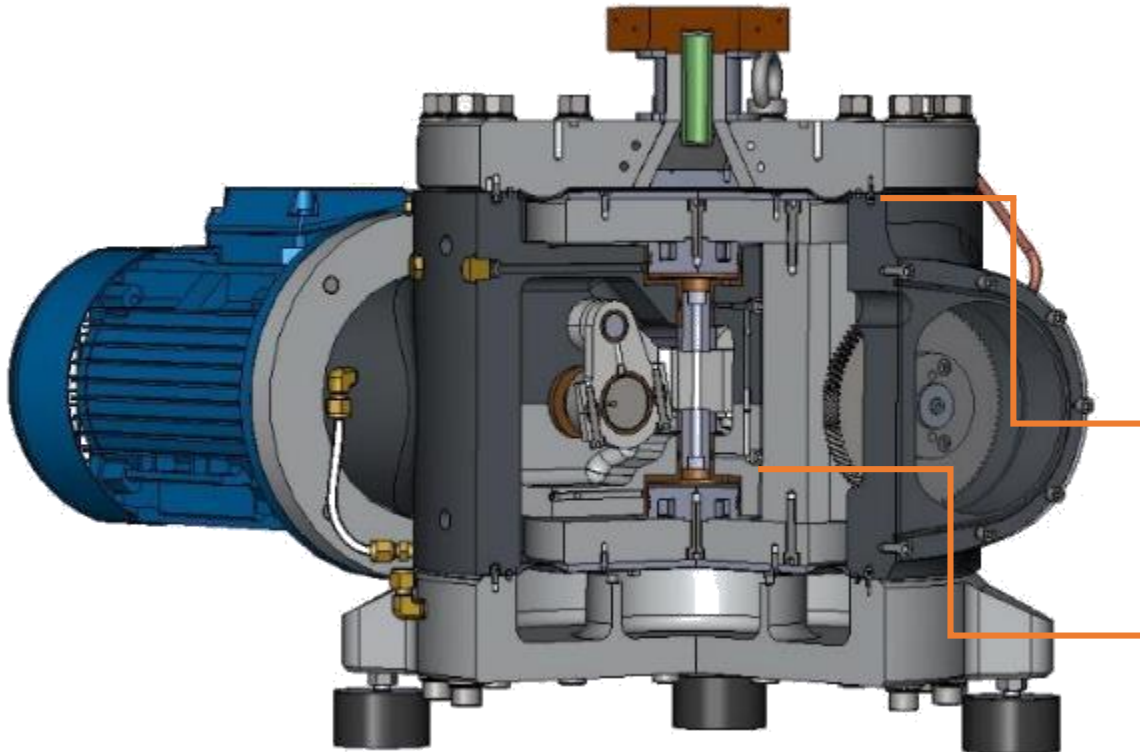
Diaphragm Pressure Wave Generator an industrial solution

Attributes

Patented diaphragm pressure wave generator delivers rugged, low maintenance and efficient cryocooling

Long life diaphragm separating the cryogenic cold head from the pulsation wave components: no impurities

Off-the-shelf drive mechanisms and components: motors, seals, bearings and controls





Pulse tube cold head

Attributes

In-line mono stage high frequency pulse tube cold head

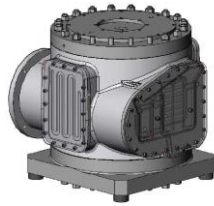
Simple to design and produce (low cost)

No moving parts – Absolutely NO MAINTENANCE

Ultra high reliability

1st Prototype of
200cc DPWG

Design of multiple products using Pulse Tube technology



2005

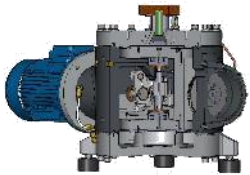
2017

2008

2011

2014

2015



The metal diaphragm
pressure wave generator
technology in 2005

1st cryocooler using a
Pulse Tube cold head

1st Prototype of
330cc DPWG

1st Prototype of
1000cc DPWG

Commercial manufacture of
PTC330 and PTC1000 units

1st Work Horse product



PTC330

Swept Volume 330cm³

Power @ 77K 480W

No Load Temperature 45K

Motor Power @ 77K 12kW

Weight 800kg

Dimensions (m) 1.9(L)x0.8(W)x1.7(H)

2nd Work Horse product



PTC1000

Swept Volume 1000cm³

Power @ 77K 1450W

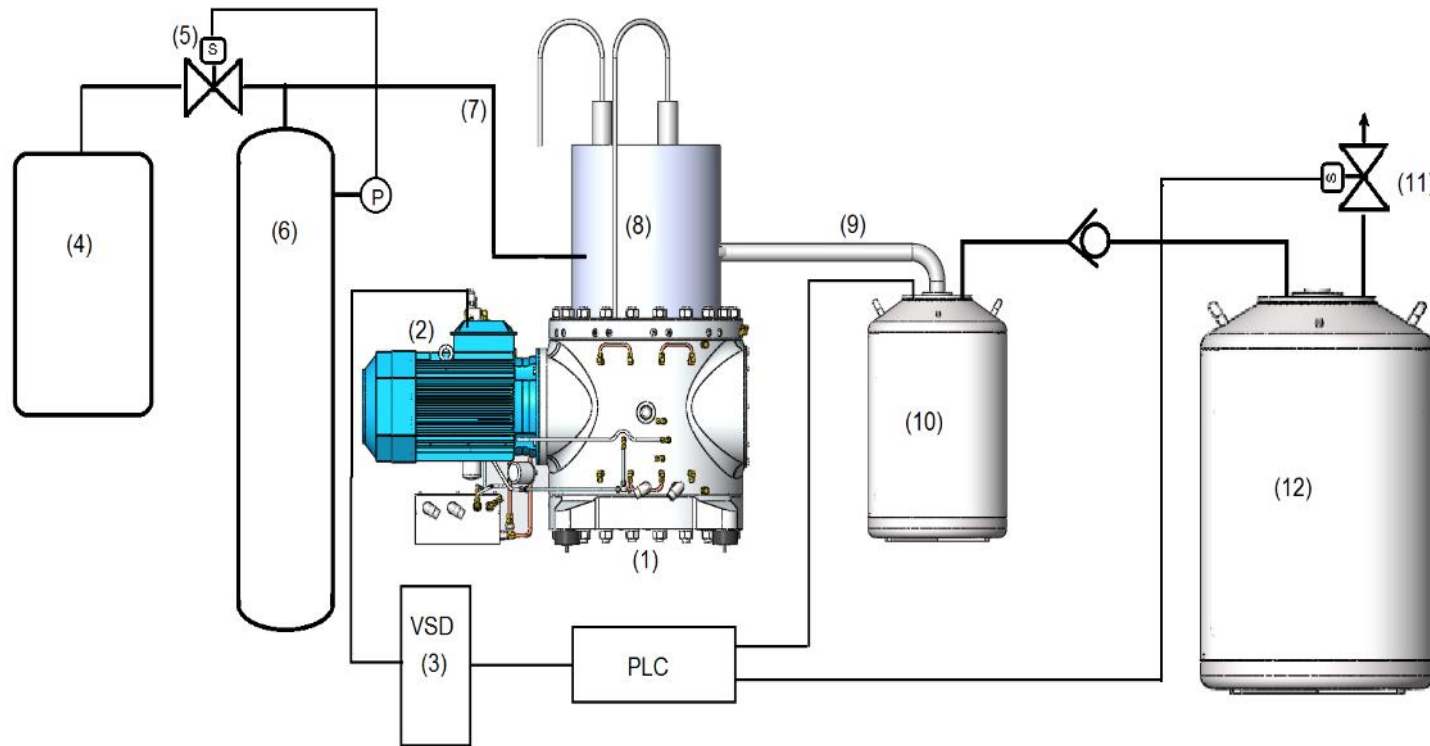
No Load Temperature 43K

Motor Power @ 77K 25kW

Weight 1300kg

Dimensions (m) 1.8(L)x1.2(W)x2.2(H)

Liquefaction System with Diaphragm Cryocooler



- Gas supply from PSA, ASU or bulk supply (1 – 30 bar)
- Condenser liquefies the gas which is stored in the pressurised dewar
- The cryocooler is effective over a large temperature range

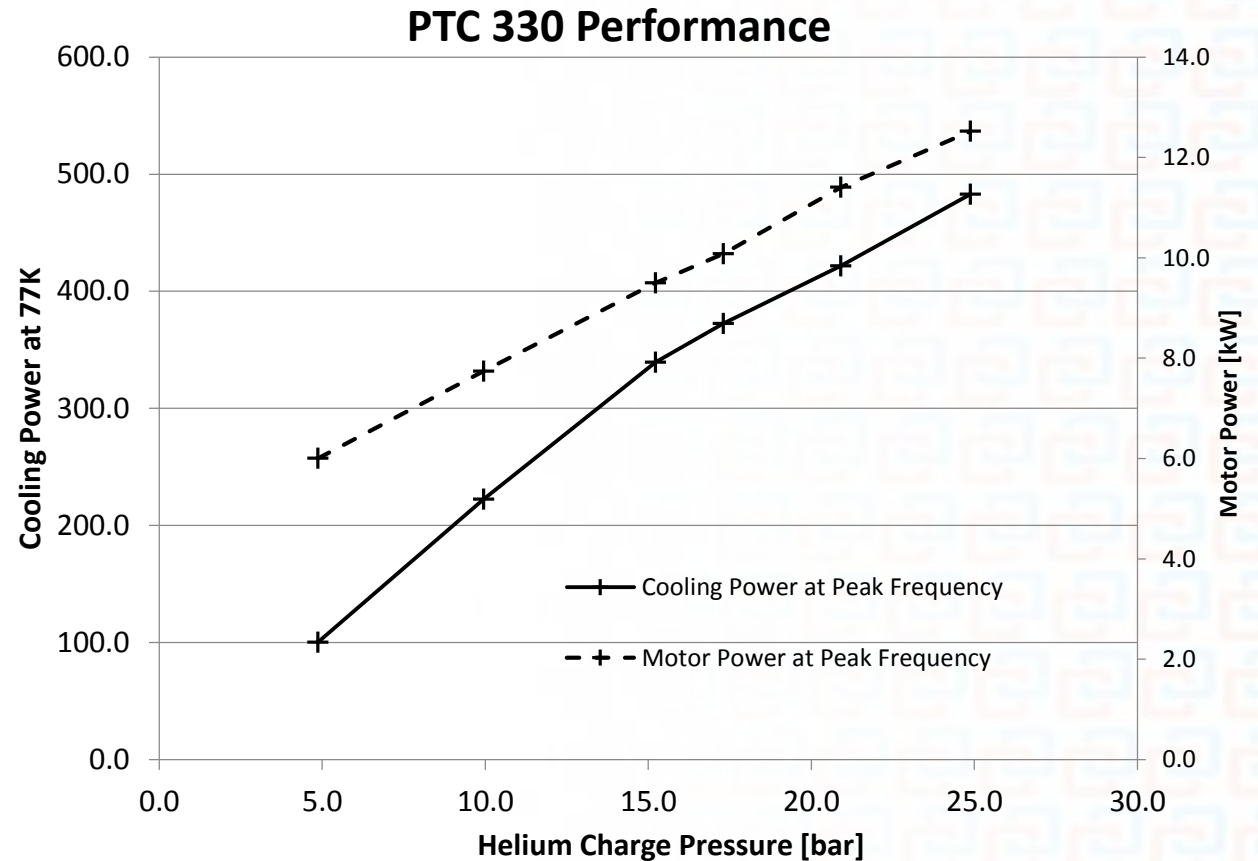


Load Matching

Cooling loads are not constant. In order to match the load we undertook development to vary the cooling power at a given temperature.

Two approaches :

1. **Frequency modulation.** This varies the cooling power by detuning from the optimum Pulse Tube frequency. However, the input power remained constant. This was undesirable due to loss of efficiency.
2. **Pressure tuning.** The helium pressure was varied over several runs. The cooling power and input power requirements reduced at lower pressure giving consistent system efficiency. The relationship between cooling power, helium pressure and motor power is shown for our PTC330 the figure.



Cascaded Cooling for increased liquefaction output

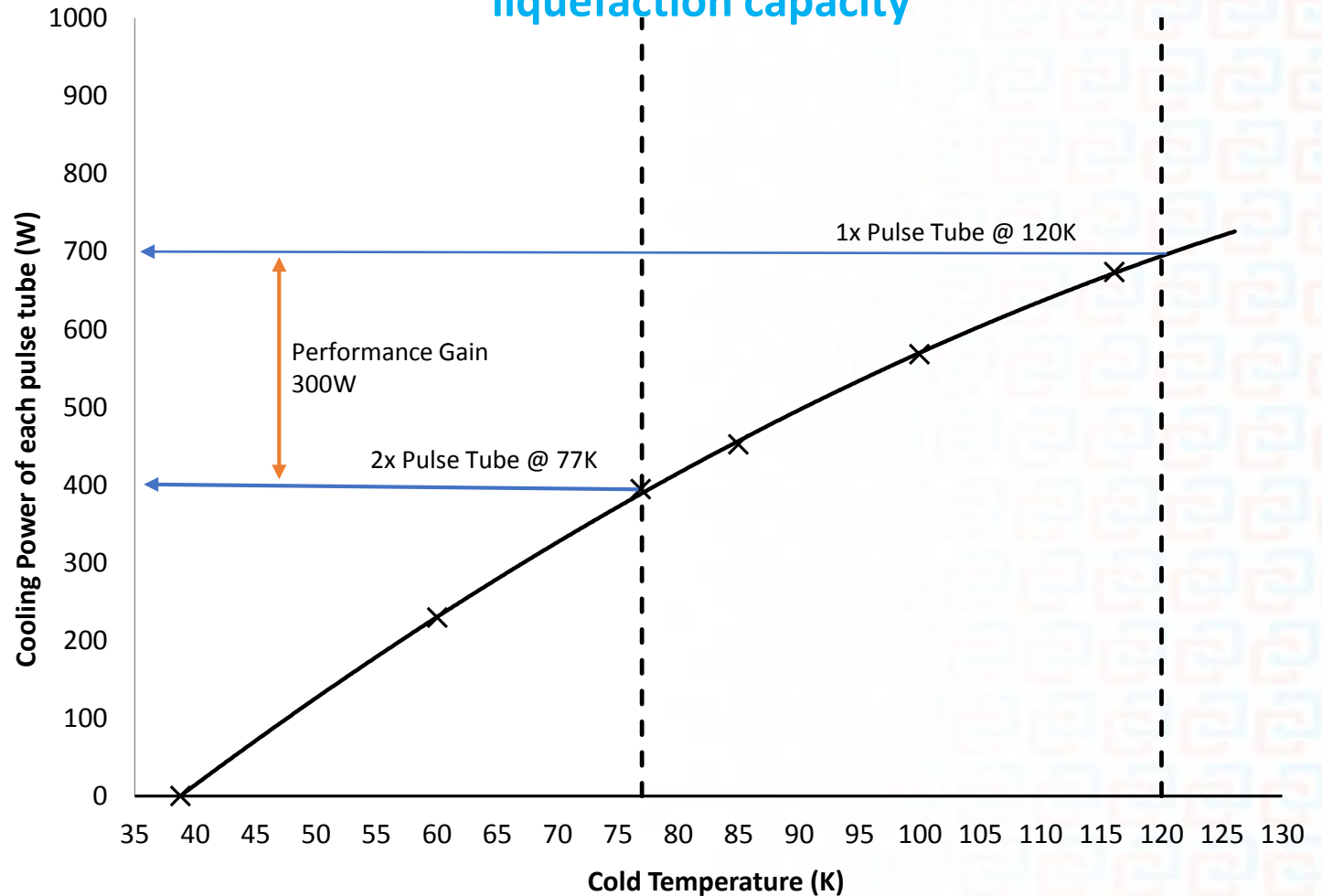
Our PTC1000 cryocooler employs three pulse tubes mounted to one Pressure Wave Generator (PWG).

Due to this configuration, we are able to pre-cool the incoming gas with one pulse tube, leaving the remaining two to do the liquefaction.

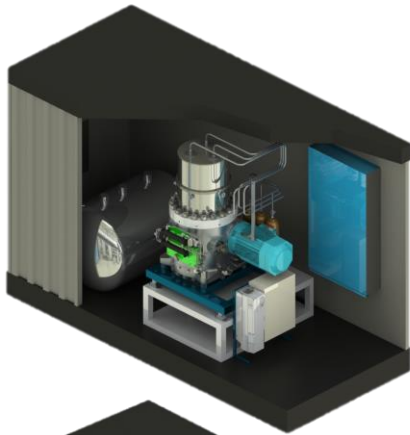
This presents a distinct advantage that heat is being removed at a higher temperature, where our cooling power is elevated.

We have shown an increase in liquefaction rate of 20% over parallel configurations.

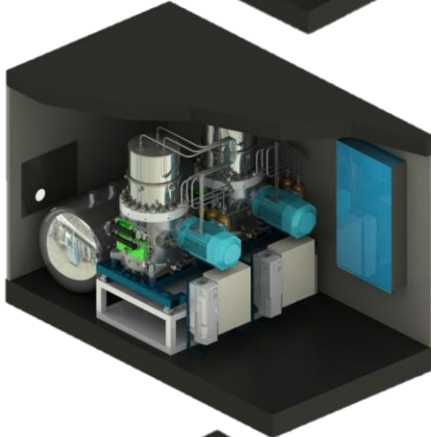
PTC1000 - Cascading the PT cold heads for more liquefaction capacity



LGU 350
350 l/day LN2
27 kW



LGU 700



LGU 1000



Development of units to meet market requirements

- Progressed technology up to 15 liters of LN2 per hour per cryocooler (PTC1000) at 77K/1bar
- Quick start up, Liquid production in <15 min.
- Modular configurations to meet customer requirements are trivial
- Tolerant of shock associated with transportation
- Palletised/containerised for ease of lifting and transportation
- Very simple on site servicing - No clean environment nor specialist & tools required